COST COMPARISON FOR MONITORING IRRIGATION WATER USE: LANDSAT THERMAL DATA VERSUS POWER CONSUMPTION DATA

Anthony Morse, **William J. Kramber**
Idaho Department of Water Resources
PO Box 83720
Boise, ID 83720-00098
tony.morse@idwr.idaho.gov
bill.kramber@idwr.idaho.gov

Richard G. Allen
Department of Agricultural and Biological Engineering
Department of Civil Engineering
University of Idaho, Kimberly Research Station
Kimberly, ID 83341
rallen@kimberly.uidaho.edu

ABSTRACT

The Idaho Department of Water Resources uses Landsat thermal data in an energy-balance evapotranspiration model called METRIC. The Department compared the costs to monitor 3,830 irrigation wells on the Eastern Snake Plain Aquifer using power consumption coefficients with the cost to monitor the wells using evapotranspiration data derived from Landsat thermal data. The cost for using power consumption coefficients was $119.32 per well and the cost for using evapotranspiration data in a proof-of-concept application was $32.15 per well. If the Department applied the proof-of-concept costs to monitoring all 5,948 wells in southern Idaho, the cost per well would drop to $22.19 because of the additional wells covered by the Landsat scenes. A simple comparison of the power consumption coefficient data with the evapotranspiration data show the evapotranspiration data are of significantly higher quality as well as being significantly less expensive.

INTRODUCTION

As with other western states, Idaho's water law is based on the doctrine of prior appropriation (Idaho Code §42:106): first in time is first in right. In order to administer water under that doctrine, the diversion of water from Idaho's rivers has been closely monitored, although ground-water pumping has not. The Idaho Department of Water Resources (IDWR) began in 1995 to measure water use from irrigation wells on the Eastern Snake Plane aquifer (ESPA) (Figure 1) to address this disparity.

IDWR maintains the water-use data in the Water Measurement Information System (WMIS) database (Table 1). WMIS had 4,843 diversion records in 2004. Of the total 4,843 diversions, 3,830 are wells measured with the Power Consumption Coefficient method. The remaining 1,013 diversions are measured using flow meters, time clocks, open-channel measuring devices such as weirs and flumes, and other methods. Over half of these non-PCC measured diversions are commercial and municipal wells.

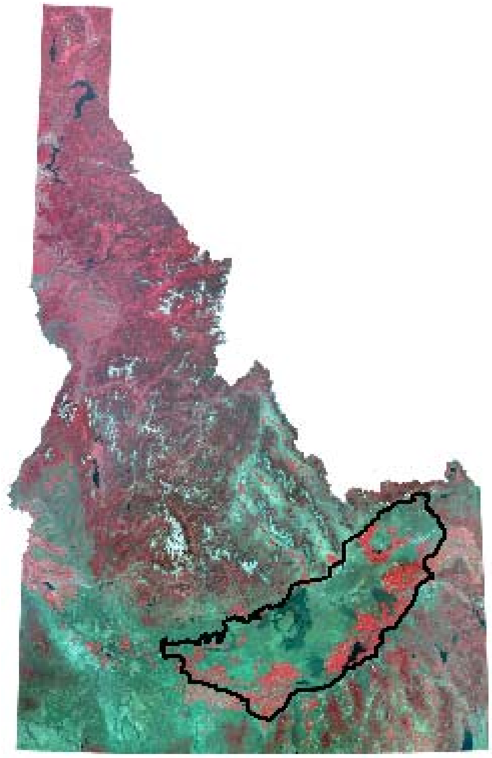

Figure 1. Landsat false-color composite of Idaho showing the location of the Eastern Snake Plane Aquifer in black.

In 2000, IDWR and the University of Idaho (UI) began work on a NASA Synergy grant to develop and apply an energy-balance model to compute and map evapotranspiration. The model is called METRIC, which is an acronym for Mapping Evapotranspiration at high Resolution with Internalized Calibration (Allen, et al., 2007, 2004, 2003, METRIC is a variation of the SEBAL model (Bastiaanssen, 1998a, 1998b). Both models compute evapotranspiration as a residual of the energy balance at the earth's surface.

Landsat's thermal infrared data are the single most important variable in energy-balance evapotranspiration models. IDWR uses the METRIC model as a low-cost, high-quality alternative to traditional methods for monitoring water use from irrigation wells. Only Landsat thermal data have the relatively small pixel size, operational status, and extensive data archive that make it possible to map evapotranspiration on a field-by-field basis.

IDWR personnel compared the costs of monitoring irrigation water use using the traditional method of power consumption coefficients with the alternative of evapotranspiration as computed by the METRIC model. The results show clearly that the use of thermal infrared data from Landsat offers significant advantages in both cost and data quality.

Reporting District	Number of Diversions
A&B Irrigation District	179
Aberdeen AF GWD	658
Bingham GWD	778
Bonneville-Jefferson GWD	216
East Measurement District	303
Falls Irrigation District	26
IDWR	105
Magic Valley GWD	495
North Measurement District	696
North Snake GWD	822
Southwest Irrigation District	300
Water District 31*	1
Water District 36A	12
West Measurement District	252
Total	**4,843**

* Over 30 wells but district reports as one annual volume

Table 1. The number of diversions in reporting districts of the Eastern Snake Plane aquifer. Of the 4,843 wells listed, 3,830 are irrigation wells.

The Cost to Monitor Wells Using Traditional Methods

IDWR and other, local, entities cooperate to monitor water use from the wells on the Eastern Snake Plane. The average cost per well is made up of three components: 1) the cost to water districts, ground water districts, and irrigation districts for contract field-work, 2) the cost of IDWR monitoring or oversight, and 3) the cost to the various districts for administrative staff time.

Ground Water Districts on the Eastern snake Plane generally contract for measuring and reporting of ground water diversions. Four of the five districts plus one irrigation district contract with the same small firm for measurement work. Exact budget figures from these districts are not readily available, but some general figures are available. The cost for measuring and reporting associated with that small firm is about $75 per well, annually. The annual water district costs for measurement of wells over the past several years has also run at about $75 per well.

The Water Distribution Section at IDWR spends approximately $103,000 per year to monitor water use in the form of 1.5 FTEs per year (3120 hours) in support of the ESPA measurement program. Support includes data management, data quality control, field audits, and training field staff in the Water Districts and Ground Water Districts. Staff time ranges from the water distribution section manager to clerical data entry, at an estimated hourly rate of about $18 per hour plus benefits. Applying this time and rate, adding the normal benefits calculations, and adding in IDWR indirect costs to address expenses related to travel and field equipment results in a total IDWR cost of about $103,000 per year.

Table 2 summarizes the estimated costs of both IDWR and the ground water districts for measuring irrigation water use in the ESPA. When all the costs are totaled, the average cost per well for monitoring irrigation water use on the Eastern Snake Plane is just over $119.00 per well.

Work by Entity	Cost
Field work by Water and Ground Water Districts	$460,100
Oversight and quality control by IDWR personnel	$103,000
Data processing by Water and Ground Water Districts	$ 14,750
Total	**$577,850**
Cost per well for 4,843 wells	$119.32

Table 2. Annual costs associated with measuring diversions on the Eastern Snake Plane aquifer.

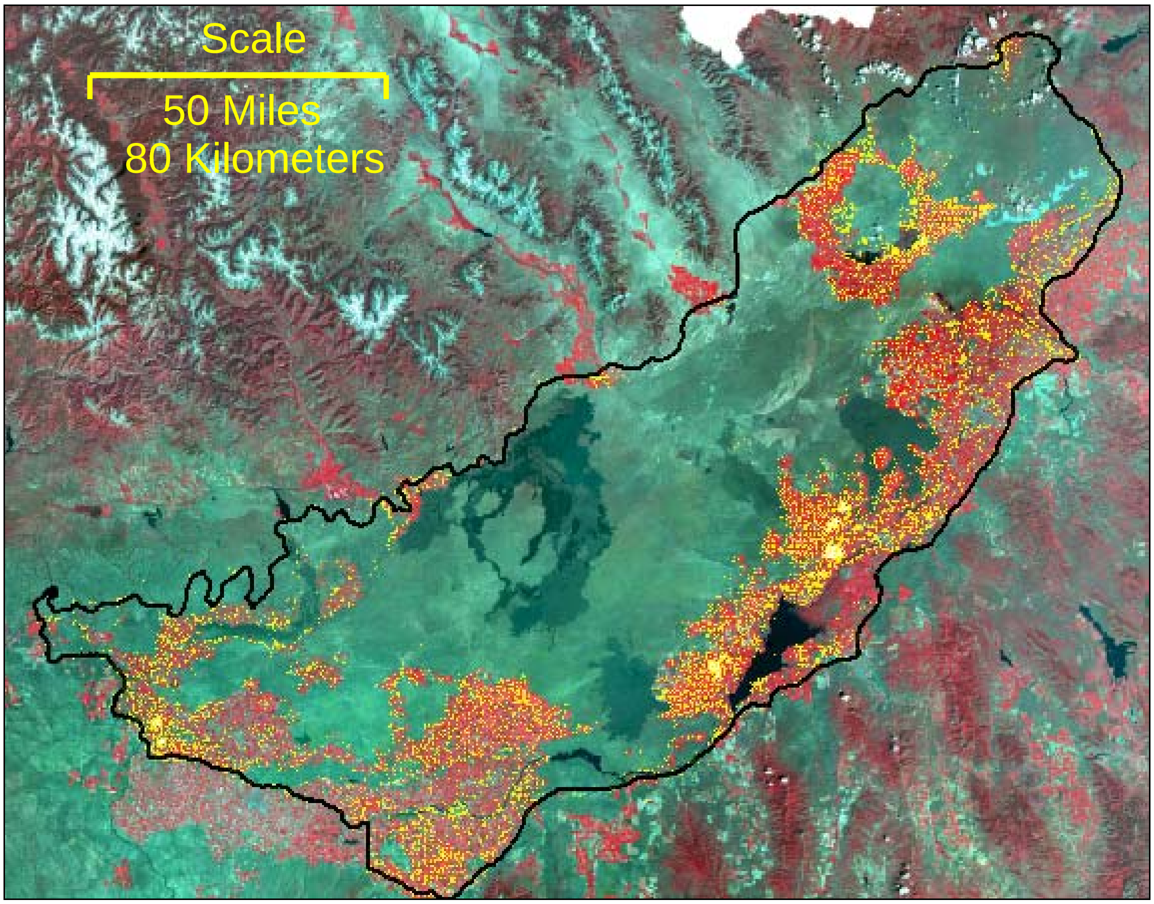

Figure 2. A Landsat false-color composite image on which is plotted the boundary of the Eastern Snake Plane aquifer in black and the locations of irrigation wells in yellow.

THE METRIC MODEL

METRIC (Mapping Evapotranspiration at high Resolution with Internalized Calibration) is an image-processing tool for computing evapotranspiration from Landsat or other satellite data. METRIC computes a complete energy balance for each pixel using the equation:

$$LE = R_n - H - G$$

where LE is the latent energy consumed by evapotranspiration, R_n is net radiation (sum of all incoming and outgoing shortwave and longwave radiation at the surface), H is sensible heat flux convected into the air, and G is sensible heat flux conducted into the ground. METRIC is a variation of the SEBAL model, which was developed in the Netherlands by Bastiaanssen (1998a, 1998b). METRIC refines its modeling of evapotranspiration by incorporating reference evapotranspiration computed from ground-based weather data.

IDWR's use of METRIC in this and other applications clearly shows that Landsat thermal data are the basis of an efficient, accurate, and relatively inexpensive procedure to map actual evapotranspiration from irrigated land throughout a growing season.

The majority of the METRIC applications have been in Idaho, where the Idaho IDWR and UI have used METRIC to compute monthly and seasonal evapotranspiration for a variety of applications in water planning and water rights administration. IDWR has used METRIC to 1) set water budgets for hydrologic modeling, 2) monitor compliance with water rights, 3) support water planning, 4) estimate aquifer depletion, and 5) estimate water use by irrigated agriculture (Morse, et al., 2003, Allen, et al., 2005). UI has applied METRIC in other parts of the United States (Allen, et al., 2005).

LANDSAT DATA PROCESSING

Description

The relationship between evapotranspiration and ground water use is important for IDWR regulatory processes. Historically, surface water diversions have been closely monitored while ground water diversions have not. Approximately 300 monitored diversions from the Snake River irrigate approximately 647,500 hectares over the Eastern Snake Plain aquifer. That aquifer also supports approximately 200,000 hectares of ground water irrigation from approximately 4,900 wells. From a logistical point alone, monitoring ground-water use is a large undertaking.

Cost

The information on cost per well is computed here in two steps. The first step is the cost per well as done for the proof-of-concept to develop a methodology. The methodology was developed using just the wells on the Eastern Snake Plane aquifer because we also have cost data for an alternative method that uses power consumption coefficients. The second cost per well is computed by extending the methodology to all of southern Idaho, which has most of the irrigation in the state.

IDWR and UI collaborated to generate an evapotranspiration map of Southern Idaho for the year 2000. It is difficult to estimate the cost of producing a seasonal evapotranspiration map in an operational environment because the year 2000 map was made over a 2-year period as part of the research and development of the METRIC model. Nevertheless, the costs can be reasonably estimated.

The cost estimate is base on processing done as part of a research and development grant. The Landsat scenes are for the year 2000. For that grant, images from nine path-row combinations were processed, three of which are needed to cover the ESPA: p39r29, p39r30, p40r30 (Figure 3). A mix of Landsat 5 and Landsat 7 images were processed to develop the year 2000 evapotranspiration data. The dates and costs are summarized in Table 3. These are ordered from the USGS Eros Data Center (EDC) through their Earth Explorer website.

The Landsat data were terrain-corrected by EarthSat, which is now called MDA Federal, Inc. MDA Federal charged IDWR $325 per image for consistent, high-quality terrain correction. The cost for the terrain-corrected Landsat data covering three nominal scenes was $29,900, as detailed in Table 3.

Path 39 Row 29			Path 39 Row 30			Path 40 Row 30		
Date	Landsat	Cost	Date	Landsat	Cost	Date	Landsat	Cost
3/16	7	$925	3/16	7	$925	3/15	5	$750
4/1	7	$925	4/1	7	$925	4/8	7	$925
5/3	7	$925	5/3	7	$925	5/2	5	$750
6/4	7	$925	6/4	7	$925	6/3	5	$750
6/20	7	$925	6/20	7	$925	6/19	5	$750
7/6	7	$925	7/6	7	$925	7/5	5	$750
7/22	7	$925	7/22	7	$925	7/21	5	$750
8/7	7	$925	8/7	7	$925	8/14	7	$925
8/23	7	$925	8/23	7	$925	8/22	5	$750
9/8	7	$925	9/8	7	$925	9/7	5	$750
9/16	5	$750	9/16	5	$750	9/15	7	$925
10/18	5	$750	10/18	5	$750	10/17	7	$925
Path-Row Total		$10,100			$10,100			$9,700
Grand Total $29,900								

Table 3. Scene dates and costs for the Landsat data processed to compute seasonal evapotranspiration for the year 2000.

The processing cost for each image varies based on several factors. A conservative estimate assumes each scene is processed independently, although often scenes within one path acquired on the same day can be processed as one, mosaicked unit. It takes about 70 hours to process the Landsat data into evapotranspiration, which equates to a cost of $2,550 per image. Therefore, the maximum cost of processing all the data would be 36 x $2,550 = $91,800. Adding the data cost to the processing cost, the total cost would be $29,900 + $91,800 = $121,700.

Very little time is needed to overlay the water-right polygons on the evapotranspiration data to compute the seasonal evapotranspiration by water-right polygon, but even if a full week is needed the cost would be $1,450 + $121,700 = $123,150. When that cost is divided by the number of wells, the result is $123,150 / 3,830 wells = $32.15 per well.

The above cost is a maximum-cost estimate in the sense that it is generated from a proof-of-concept in a restricted area. The cost per well will be lower for an operational program for 2 reasons. The first reason is that the proof-of-concept study included only the wells on the Eastern Snake Plane aquifer, not all wells within the Landsat scenes. The second reason is that the cost for the proof-of-concept includes developing a workflow for the process.

Cost for an Operational Program

Based on the results from the proof-of-concept, IDWR can estimate the cost to monitor water use from all the irrigation wells in southern Idaho on an operational basis. Some differences in cost between proof-of-concept and operational are inevitable. A proof-of-concept is not an efficient implementation, and the METRIC model has evolved, becoming at once both more streamlined in its implementation and more complex in its function. Nevertheless, applying the proof-of-concept cost to an operational program is illustrative.

Approximately 86% of the irrigated land in Idaho is covered by five nominal Landsat scenes. Data for five separate nominal scenes have to be purchased and processed as illustrated by Figure 3.

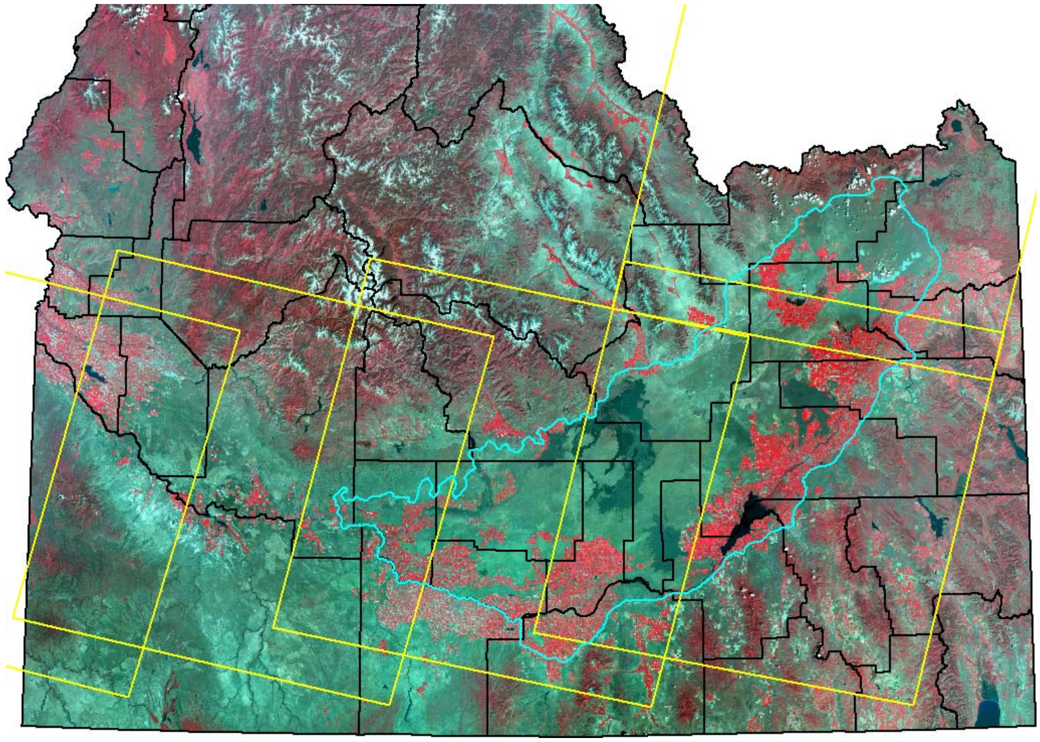

Figure 3. The five nominal Landsat scenes that cover southern Idaho. The Eastern Snake Plane aquifer, which supports the wells used in the proof-of-concept, is outlined in light blue.

The cost for data purchase is $750 x (5 path-rows) x 8 (dates per row) = $30,000. The cost to process the data is $2,550 x 40 path-row-data combinations) = $102,000, for a total cost of $132,000.

The five scenes cover approximately 86% of Idaho's irrigated agricultural acreage in 2002 (USDA, 2005). If the scenes also cover 86% of Idaho's 6,924 irrigation wells, the scenes include 5,948 wells. The cost per well for an operational system would be $132,000 / 5,948 = $22.19 per well, which is approximately 18% of the $119.32 for using power consumption coefficients. The costs are summarized in Table 4.

Method	Number of wells	Total Cost	Cost per Well
Power Consumption Coefficients	3,830	$456,995	$119.32
Landsat Evapotranspiration Proof-of-Concept	3,830	$123,134	$ 32.15

Landsat Evapotranspiration Operational	5,948	$132,000	$ 22.19

Table 4. Summary of the cost per well to compute agricultural water use operationally in Idaho.

OTHER CONSIDERATIONS

Timeliness

Using the METRIC evapotranspiration model is a complex task, and good results will require considerable expertise, training, and experience. Those ramp-up costs are not considered here.

Water use from evapotranspiration data are available sooner than are pumpage data computed from power consumption coefficients. The Landsat scenes are processed as they are acquired throughout the growing season, and not left until all scenes are in hand at the end of the growing season. Power consumption coefficient data are reported to IDWR by power companies between December and February for the previous growing season. As a result, final water-use data can be available during the fall of the growing season, well in advance of delivery of the first power consumption coefficient data.

Data Quality

Energy-balance models have been shown to compare favorably to measured evapotranspiration. Allen, et al. (2007) compared METRIC evapotranspiration data to evapotranspiration as measured by precision lysimeters, and found differences as low as 4% for seasonal evapotranspiration totals. Bastiaanssen, et al. (2007), using SEBAL, which is a very similar to METRIC, conclude that seasonal evapotranspiration can be estimated with an accuracy of 95%.

Lysimeter data are no longer available in Idaho, but inspecting the power consumption data and the evapotranspiration is worthwhile. The two data sets used 184 field-well combinations. Figures 5a and 5b show the scatter within each individual variable of the dataset in Figure 4 plotted with AgriMet evapotranspiration data. The AgriMet data show the evapotranspiration extremes of alfalfa and peas, and were recorded for the year 2000 at the U.S. Bureau of Reclamation AgiMet station in Aberdeen, Idaho. The Aberdeen Station is within approximately 32 km. of these fields, and is representative of them.

The two plots reveal useful information. In Figure 5a, nearly all the METRIC evapotranspiration observations fall between the extremes of evapotranspiration, which are the lowest at 365 mm for peas and highest at 890 mm for alfalfa. Further, there is a distinct “floor” at approximately 600 mm of evapotranspiration, which is an indication of a practical minimum level of evapotranspiration from irrigated agriculture. Most of the data fall well above peas, the local crop that uses the least water.

Contrast the METRIC evapotranspiration pattern of Figure 5a with the pattern for power consumption as illustrated by Figure 5b. The power consumption data are not consistent at either the high end of the chart or at the low end. There is no "floor" evident to show that there is a minimum level of pumping needed to support an irrigated crop. In fact, the power consumption data indicate that some fields are getting no water at all. The reliability of the dataset is called into question by the lack of patterns that reflect irrigation practice on the Eastern snake Plans aquifer, and by the abundance of data at the extreme low end of the chart.

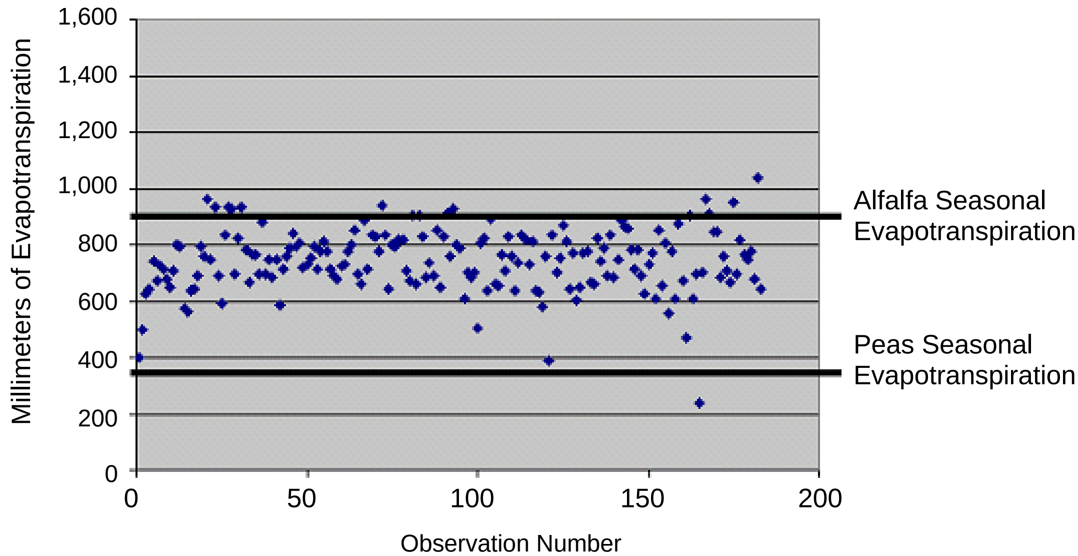

Figure 5a. April to October 2000 METRIC water use computed from the METRIC evapotranspiration model compared with AgriMet evapotranspiration extremes.

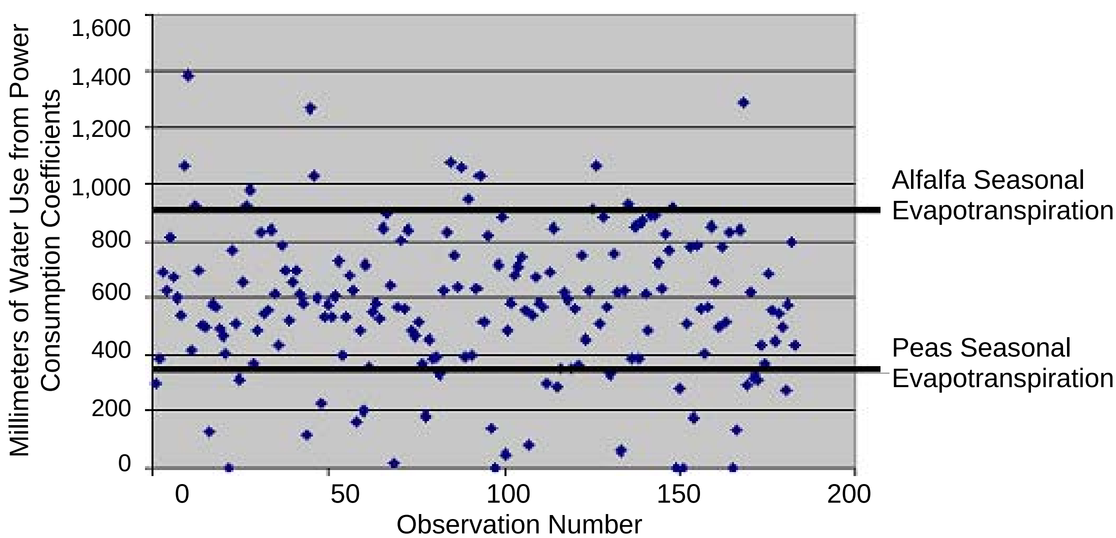

Figure 5b. April to October 2000 water use computed using power consumption coefficients compared with AgriMet evapotranspiration extremes.

CONCLUSIONS

1. Evapotranspiration computed by an energy balance model using Landsat thermal data is a viable alternative to traditional methods of monitoring agricultural water-use, such as power consumption coefficients.

2. For monitoring agricultural water use from irrigation wells, evapotranspiration data are more cost-effective than power consumption data by a factor of greater than 5 to1.

3. Evapotranspiration data are more reliable than are power consumption data.

REFERENCES

Allen, R.G., M. Tasumi, A. Morse, R. Trezza, J.L. Wright, W. Bastiaanssen, W. Kramber, I. Lorite-Torres, and C.W. Robison; 2007; Satellite-Based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC) – Applications; American Society of Civil Engineers, Journal of Irrigation and Drainage Engineering; vol.133, no. 4, pps. 395-406

Allen, R.G., A. Morse, M. Tasumi, W.J. Kramber, W. Bastiaanssen; 2005; Computing and Mapping of Evapotranspiration; Chapter 5 in Advances in Water Science Methodologies; U. Aswathanarayana, Ed.; A.A. Balkema Publishers; Leiden, The Netherlands

Allen, R.G., M.Tasumi and I. Lorite-Torres; 2003; High Resolution Quantification of Evapotranspiration from Imperial Irrigation District. Research Completion report (phase I) submitted to MWD, December 2003. 130 p.

Allen, R.G., M. Tasumi, A. Morse, and R. Trezza; 2004; A Landsat-based Energy Balance and Evapotranspiration Model in Western US Water Rights Regulation and Planning. *J. of Irrig. and Drain. Sys;* vol 19, pp 251-268

Bastiaanssen, W.G.M., R.G. Chavez, A. Alsulaimain, and M. Ahmad; 2007; Estimation of groundwater extraction on irrigated lands in arid zones from thermal infrared satellites; Journal of Geohydrology; in press

Bastiaanssen, W.G.M., E.J.M. Noordman , H. Pelgrum, G. Davids, B.P. Thoreson and R.G. Allen. 2005. SEBAL model with remotely sensed data to improve water resources management under actual field conditions. *J. Irrig. and Drain. Engrg,* ASCE 131(1):85-93.

Bastiaanssen, W.G.M., M. Menenti, R.A. Feddes, and A.A.M. Holtslag; 1998a; A remote sensing surface energy balance algorithm for land (SEBAL): 1. Formulation. *J. Hydrology,* 212-213, p. 198-212.

Bastiaanssen, W.G.M., M. Menenti, R.A. Feddes, and A.A.M. Holtslag; 1998b; The Surface Energy Balance Algorithm for Land (SEBAL): Part 2 validation, *J. Hydrology* , 212-213: 213-229

Hutson, S.S., N.L. Barber, J.F. Kinny, K.S. Linsey, D.S. Lumia, and M.A. Maupin; 2004; Estimated Use of Water in the United States in 2000; U.S. Geological Survey Circular 1268; U.S. Government Printing Office, Washington, D.C.

Kramber, W.J., A. Morse, B. Harmon, and H. Anderson; 1997; "Mapping 80 years of change in irrigated agriculture," Proceedings of the 1997 ACSM/ASPRS Annual Convention; Bethesda, MD, pp 367-372.

MacConnell, W.P.; 1973; Massachusetts Map-Down Publication 97, Cooperative Extension Service, University of Massachusetts.

Morse, A., W.J. Kramber, R.G. Allen, M. Tasumi; 2003; Preliminary Computation of Evapotranspiration by Land Cover Type Using Landsat TM Data and SEBAL; Proceedings of the 2003 International Geophysical and Remote Sensing Symposium; Toulouse, France

Morse, A., W.J. Kramber, R.G. Allen, M. Tasumi; 2004; Use of the METRIC Evapotranspiration Model to Compute Water Use by Irrigated Agriculture in Idaho; Proceedings of the 2004 International Geophysical and Remote Sensing Symposium; Anchorage, AK.

Solley, W. B., R. R. Pierce, and H.A. Perlman; 1998; Estimated Use of Water in the United States in 1995; U.S. Geological Survey Circular 1200, U.S. Government Printing Office, Washington, D.C.

Tasumi, M., R.G. Allen., R. Trezza, and J.L. Wright; 2005; Satellite-Based Energy Balance to Assess Within-Population Variance of Crop Coefficient Curves; ASCE J. Irrigation and Drainage Engineering; vol. 131, no. 1; pp 94-109